Restoration of Freshwater Intertidal Habitat Functions at Spencer Island, Everett, Washington

Curtis D. Tanner[1,5]
Jeffery R. Cordell[2]
Jane Rubey[3]
Lucinda M. Tear[4]

Abstract

In November 1994 dikes were breached around Spencer Island, restoring tidal inundation and connections to the Snohomish River estuary, Washington. Approximately 23.7 ha (58.5 ac) of palustrine wetlands previously dominated by *Phalaris arundinacea* (reed canarygrass) now experience diurnal tides and are in the process of transition to a freshwater tidal system. It was expected that brackish water would accompany the return of tidal influence to the site, but post-project monitoring has revealed little evidence of salinity. Pre- and post-project monitoring of changes in habitat function included aerial photography, vegetation and fish sampling, and benthic prey studies. To date site changes include (1) die back of pre-project vegetation, development of tidal mudflat, and emergent wetland habitats, with recruitment of vegetation typical of freshwater tidal wetlands; (2) presence of juvenile coho, chum, and chinook salmon that feed on invertebrate prey typical of the site; (3) presence of three distinct benthic invertebrate assemblages in the project area; and (4) some invasion by *Lythrum salicaria* (purple loosestrife). The unexpected freshwater conditions, the lack of published information about tidal oligohaline marshes in the Pacific Northwest, the use of the site by endangered salmonid species, and the invasion by an undesired plant species underscore the importance of long-term monitoring at the site.

Key words: dike breach, intertidal wetland, invertebrates, restoration, salmon (*Oncorhynchus* spp.), vegetation community.

[1]U.S. Fish and Wildlife Service, Puget Sound Program, 510 Desmond Dr. SE, Suite 102, Lacey, WA 98503, U.S.A.
[2]University of Washington, Wetland Ecosystem Team, School of Aquatic and Fishery Sciences, Box 355020, Seattle, WA 98195-5020, U.S.A.
[3]Shorelands and Environmental Assistance Program, Washington Department of Ecology, P.O. Box 47600, Olympia, WA, 98504-7600, U.S.A.
[4]Parametrix, Inc., 5808 Lake Washington Blvd. NE, Suite 200, Kirkland, WA 98033, U.S.A
[5]Address correspondence to C. D. Tanner, curtis_tanner@fws.gov.

Introduction

Puget Sound Intertidal Wetland Loss

Historically, large areas of intertidal wetlands were associated with the major river deltas of Puget Sound. European settlement during the late 1800s and early 1900s led to conversion of intertidal wetlands to human use by diking and filling. It is estimated that for the 11 major river deltas in Puget Sound, less than 40% of the historic vegetated estuarine wetlands remain. The Snohomish River is estimated to have once supported 39 km^2 of estuarine wetlands; less than 10 km^2 exist today (Bortleson et al. 1980). To recover lost estuarine wetlands and associated functions, breaching dikes is a priority for wetland conservation in the region (Puget Sound Water Quality Authority 1991; Puget Sound Water Quality Action Team 2000).

Study Area

Spencer Island is located between Union and Steamboat Sloughs near Everett, Washington in the Snohomish River estuary at approximately river kilometer 6.1 (Fig. 1) (47°59′30″ N 122°9′30″ W). The island was diked in the early 1900s and used primarily for grazing, until jointly purchased in 1989 by Snohomish County Parks and Recreation Department (County) and the Washington Department of Fish and Wildlife (WDFW). The County manages the south half of the island for nonconsumptive recreation, including hiking and bird watching. WDFW manages the north half of the island for waterfowl breeding and consumptive and nonconsumptive wildlife oriented recreation. The system of dikes, tidegates, and ditches functioned to preclude daily tidal inundation and seasonal riverine flooding. Spencer Island is approximately 166.7 ha (412 ac); the restoration area is limited to 23.7 ha (58.5 ac) on the southern portion of the island (Fig. 2).

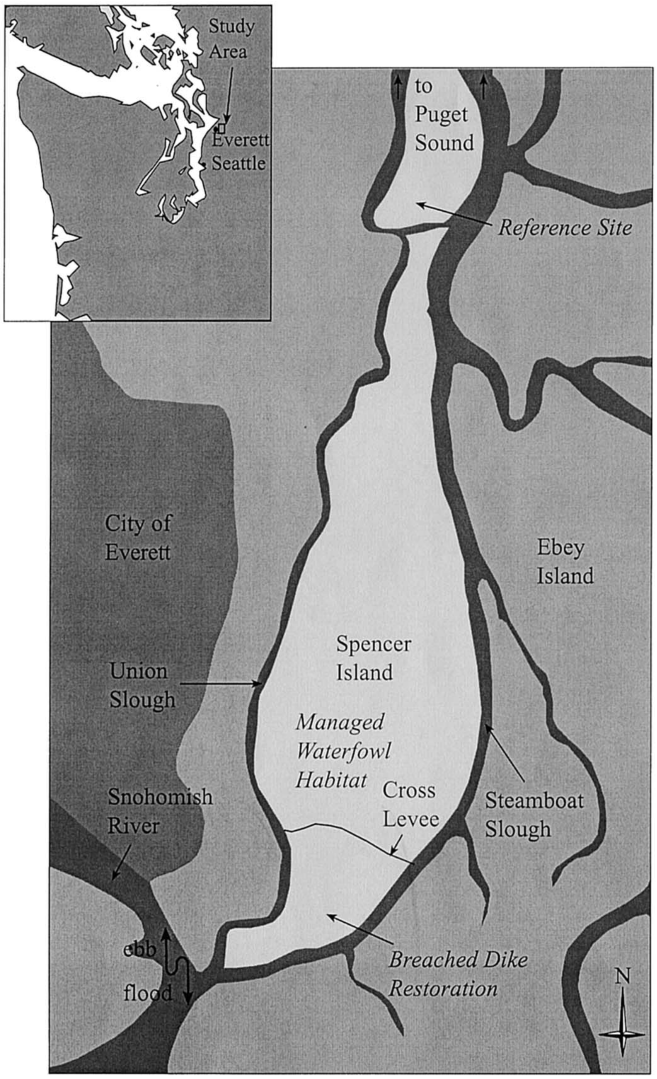

Figure 1. Location of breached-dike restoration site and reference site at Spencer Island, Washington.

Before restoration the site was characterized by dense monotypic stands of the invasive species *Phalaris arundinacea* (reed canarygrass) that covered approximately two-thirds (15.5 ha) of the restoration area. Elevation in the areas dominated by *P. arundinacea* ranged from 0.2 to 3.0 m mean sea level. Large patches of *Typha latifolia* and *T. angustifolia* (cattail) occurred in some lower elevation areas within the *P. arundinacea*-dominated area. Submerged aquatic vegetation was present in channels which surrounded and bisected the project area.

Vegetation in higher elevation habitats (i.e., spoil piles and dikes) outside of the *P. arundinacea*-dominated area was comprised primarily of non-native blackberries (*Rubus discolor* and *R. laciniatus*). In the east and southern third of the site *P. arundinacea* and blackberry graded into a forested wetland area comprised of canopy-forming *Alnus rubra* (red alder), *Salix* spp. (willow), *Populus trichocarpa* (black cottonwood), and *Picea sitchensis* (Sitka spruce) and an understory of mixed shrubs and herbaceous emergents.

Methods and Materials

Restoration

Restoring tidal influence to Spencer Island was anticipated by project planners to meet a variety of goals. These included reestablishing tidal conditions by reconnecting the site to the estuary, increasing habitat diversity by displacing *P. arundinacea*-dominated areas with native tidal wetland plant communities, and providing habitat for juvenile salmon (C. Tanner, unpublished data). A site 3.2 km downstream from the project area that had breached naturally between 1965 and 1970 provided a reference site (Fig. 1) of expected vegetation communities and habitats (Cunningham & Polayes-Wein, unpublished data).

Because dike-breach restoration was not consistent with waterfowl management activities conducted by WDFW in northern sections of the island, the largest construction activity was an approximately 760 m (2,500 ft) internal cross levee (Fig. 2) to restrict tidal influence to the southern portion of the island and avoid flooding of WDFW property. After construction of the cross levee and the installation of water control structures in the cross levee, two dike breaches approximately 15 m (50 ft) in width and one 60 m (200 ft) were excavated in November 1994 (Fig. 2). As a result tidal inundation, with a maximum diurnal tide range of approximately 4 m, was restored to the site.

Community Change Analysis

Annual color infrared aerial photographs of the site were taken in 1994, before the dike breach, and each year thereafter, except 1996. Photographs were taken during low tide near solar noon in August during the peak growing season. Scales of the photography include 1:1,200 full-island exposure, 1:800 stereo pairs, and 1:200 enlargement. These images were digitized in ERDAS Imagine format for use in ArcView (ESRI, Redlands, CA, U.S.A.).

Ground truthing was conducted after the annual aerial flights to identify vegetation community signatures in the photographs. Major vegetation communities were mapped using GIS ArcView software for the years 1994, 1995, 1997, and 1998. Comparison of pre- and post-breach communities consisted of analyzing changes in vegetation distribution and areal extent.

Vegetation Studies

The intent of the monitoring design was to characterize differences among vegetation communities and charac-

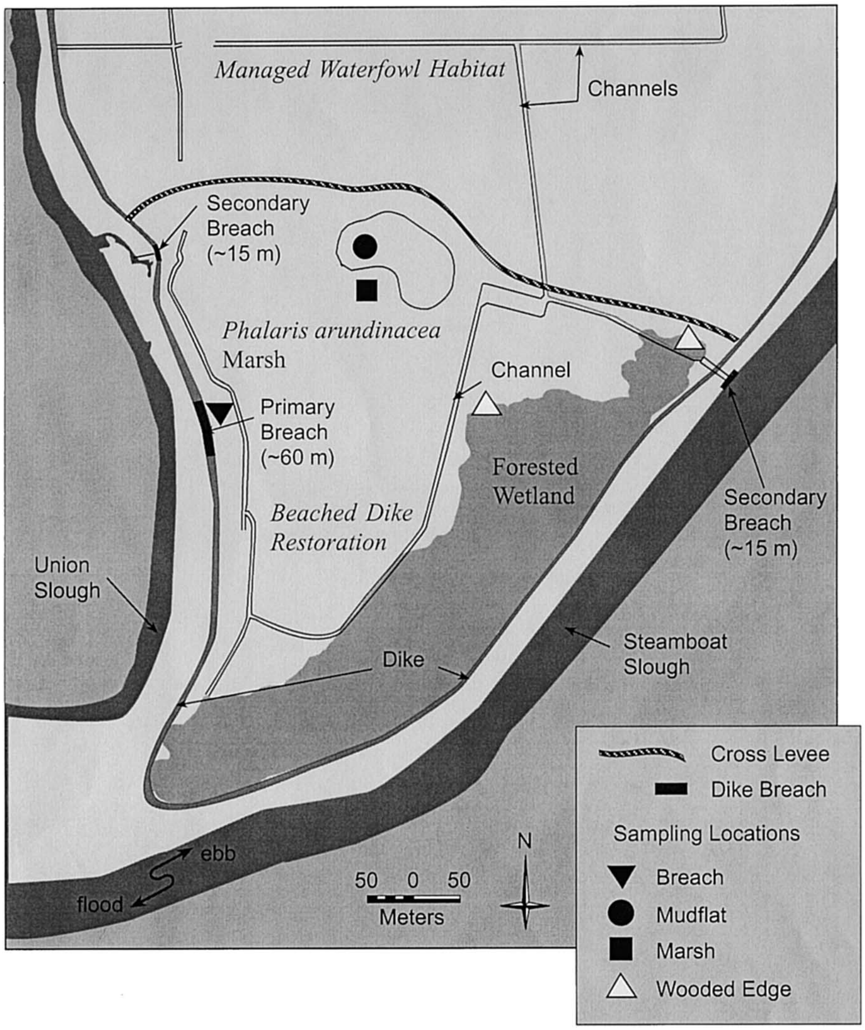

Figure 2. Spencer Island, Washington restoration project and reference area features and sampling locations.

terize changes in species composition and relative abundance over time. We hypothesized that the abundances of species that were most abundant before the dike was breached would be reduced and that post-breach communities would consist of an increasing number of native species as time progressed.

Areas of *P. arundinacea* marsh, emergent marsh/forest transition, and forest species associations were sampled separately due to differences in species composition. A global positioning system (GPS; Trimble, Sunnyvale, CA, U.S.A.) was used to locate sampling areas and collect data in the *P. arundinacea* marsh. It was not possible to use GPS in the other two habitats because of the impassable conditions created by blackberry thickets in the transition community and canopy vegetation in the forest community that prevented satellite communication.

In 1994 six transects were established along the west side of the emergent marsh area and extended 90 degrees east to the edge of the forested area on the eastern third of the island. A seventh transect running due south from the southernmost transect was established. Vegetation present in point quadrats (Greig-Smith 1964) placed every five paces (approximately 5 m) along the transects were noted and georeferenced using GPS.

The impassability of the transition area and canopy cover in the forested area precluded use of GPS in these two zones. The transition community was subdivided into wet transition and dry transition. Each of these communities and the forested community were sampled using a plot sampling design. Three 100-m^2 (10×10 m) plots were randomly located in each community type, and 48 random point quadrats were sampled in each plot. In 1995 it was possible to sample only one plot. The plot sampled was in the forested area ($n = 100$ point quadrats). In 1997 sufficient funding to conduct plot sampling was not available. Volunteers conducted transect sampling under the guidance of one of the authors along the seven transects in the emergent area. The size of each sampling unit was changed from a point quadrat to a 5 ×

5-cm quadrat to minimize between-observer error with respect to small-scale variability in plant locations. Impassable vegetation in the transition communities had died back, so transects were extended from the emergent area into the transition and forested communities. This design was used through the summer of 1999.

Along transects and within plots percent frequency of a species was estimated as X/n, where X is the number of quadrats in which the species was identified and n is the total number of quadrats sampled along the transect or in the plot. Because the quadrats along sampling transects were (approximately) equally spaced, the total number of quadrats per transect varied with the length of the transect. Data were summarized by transect and by plot.

Fish Sampling[6]

In 1997 fish were sampled approximately once every 3 weeks from 4 March to 18 June during the period of juvenile salmon outmigration. During six sampling events fish were collected in mudflat, marsh, and wooded edge habitats that corresponded to the distribution of invertebrate prey assemblages (Fig. 2).

Floating small-mesh gillnets were used in each habitat, and a fyke trap was deployed in a distributary channel within the restored area. Nets were set during low tide, left in place through high tide, and retrieved during the subsequent low tide. In addition, a beach seine was used at high tide over the mudflat site and near the large breach on 17 April to supplement the other gear types.

During 1998 and 1999 sampling occurred approximately twice monthly, from early April through mid-June. In both years a total of six sampling events were completed. Because of low numbers of fish captured with the floating gillnets and greater success with the beach seines, beach seines were used in 1998 and 1999 studies (Cordell et al. 1999). Because beach seines could not be deployed effectively in marsh or forested habitats, the sampling locations were modified to include areas in the large channel area adjacent to the primary breach and on a mudflat adjacent to the cross levee (Fig. 2).

In all years fish were identified to species and counted. Fork length was recorded for all salmonids, and subsamples of up to 10 of each species were then fixed in a 10% formaldehyde solution for later stomach content analysis. All fish not preserved were allowed to recover in a bucket of fresh water and then released. Methods for diet studies were comparable with those described by Cordell et al. (1999).

[6]Detailed method and results for Spencer Island fish and invertebrate studies can be found in Cordell et al. (1998, 1999, 2001) or in online technical reports at http://www.fish.washington.edu/Publications/index.html.

Invertebrate Sampling

Assemblages of two categories of invertebrates known to be important to juvenile salmonids were evaluated in 1997: benthic invertebrates and fallout (drift) insects. The intent was to determine whether the breached-dike site was producing typical juvenile salmon prey. Invertebrates were sampled three times during the period of fish sampling in the mudflat, marsh, and forest edge habitats (Fig. 2). Sampling was also conducted at the undiked reference area downstream from the project area (Fig. 1). Reference sample locations were established in an unvegetated mudflat, *Carex lyngbyei* (Lyngby sedge)-dominated marsh, and wooded edge to correspond with restoration site habitats. Benthic invertebrates were collected with plastic cores. Fallout insects were collected using traps consisting of floating rectangular storage bins partially filled with several centimeters of ethylene glycol based antifreeze.

In the laboratory taxa listed in the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991) as important prey resources for salmonids were identified to the taxonomic level defined in that document. In addition, invertebrates that have been demonstrated to be important juvenile salmon prey subsequent to publication of the Estuarine Habitat Assessment Protocol were identified to family (insects) or species (crustaceans) level. Other organisms were typically identified to higher taxonomic groupings.

Results

Community Change Analysis

In 1994 (Fig. 3a) the pre-breach project area consisted of a forested wetland in the eastern third of the site and a *P. arundinacea*-dominated emergent marsh in the western two-thirds. Total area of *P. arundinacea* was estimated to be 10.9 ha (28 ac) (Table 1). Within the *P. arundinacea* patches *Typha* spp. were typically found adjacent to pools of standing water. Channels and areas of ponded water were observed.

In 1995 (Fig. 3b) the immediate impacts on the vegetation communities from the dike breach and tidal inundation were apparent. The forest cover quickly began to die off. The lower elevation (<1.3 m MSL) areas of *P. arundinacea* marsh became stressed as evidenced by lower stem density and greater interspersion of open water and/or mudflat. During low tide water remained in channels and depressions.

By 1997 (Fig. 3c) the *P. arundinacea* marsh had begun to separate into higher elevation, vegetated areas, and lower elevation mudflat areas. The transition and forest communities had become a mixed community of shrub species, persistent and nonpersistent herbaceous emergents. Many facultative wetland species remained on

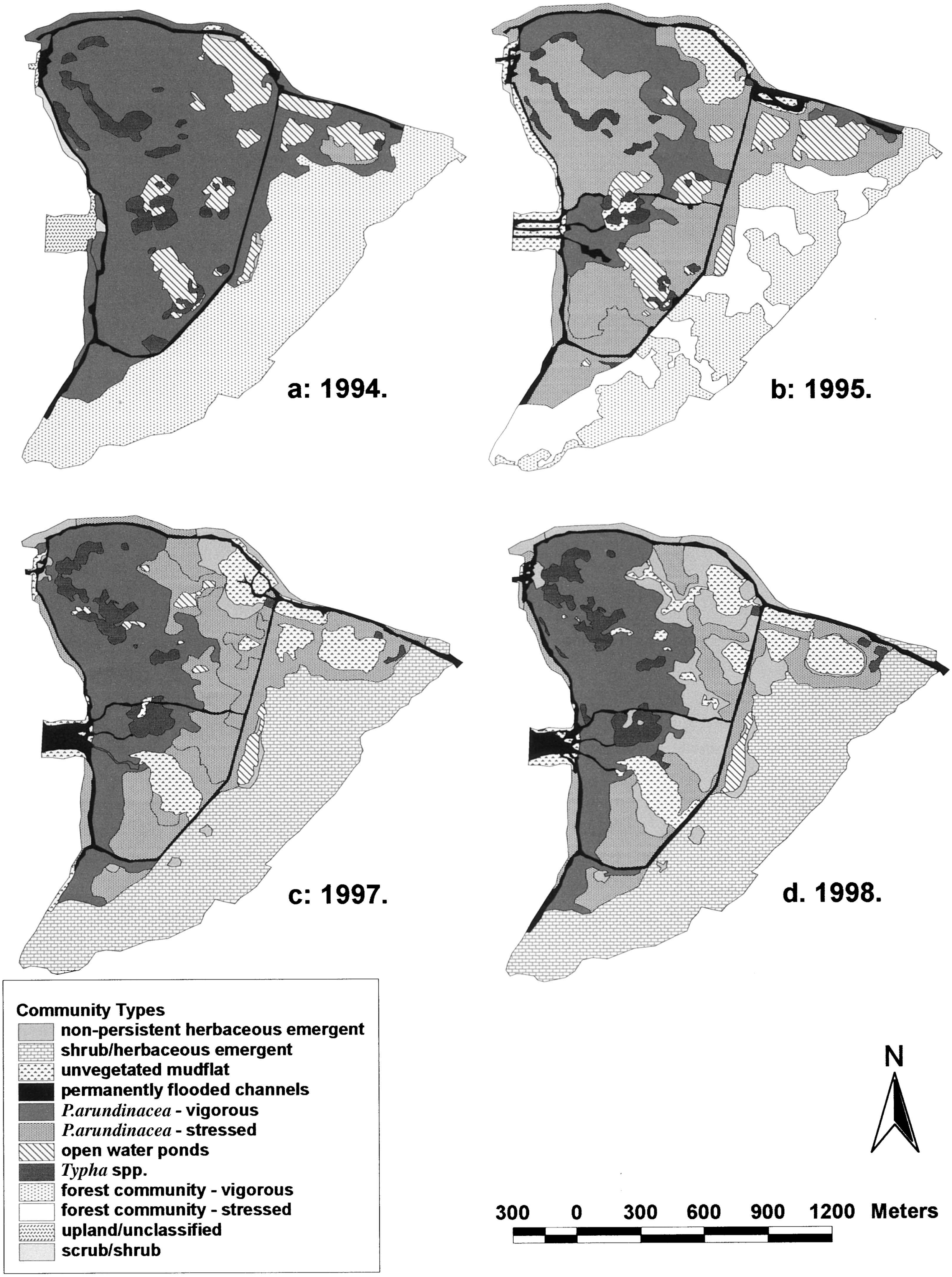

Figure 3. Vegetation communities on Spencer Island, Washington from (a) 1994 (pre-breach) through post-construction: (b) 1995, (c) 1997, and (d) 1998.

Table 1. Areal extent (hectares) of vegetation communities delineated from aerial photographs of Spencer Island, Washington, 1994–1998.

Community Type	*1994*	*1995*	*1997*	*1998*
Nonpersistent herbaceous emergent	0.1	0.0	0.7	3.4
Shrub/herbaceous emergent mixed	0.0	0.0	7.5	7.4
Unvegetated mudflat	0.1	1.3	2.0	2.0
Permanently flooded channels	0.7	1.0	1.0	1.2
P. arundinacea—vigourous	10.8	3.0	5.3	5.1
P. arundinacea—stressed	0.1	8.5	5.9	3.4
Open water ponds	1.9	1.5	0.3	0.2
Typha spp.	1.1	0.7	0.9	1.0
Forest community—vigorous	7.9	4.4	0.0	0.0
Forest community—stressed	0.0	3.1	0.0	0.0
Upland/classified	0.8	0.0	0.0	0.0
Scrub/shrub	0.1	0.0	0.0	0.0
Total	23.7	23.7	23.7	23.7

elevated hummocks within these areas. Forest canopy species had died, and dead trees had begun to fall.

Unvegetated areas were more numerous, but standing water became less prevalent as previously pooled areas became connected to tidal channels. Minor depressions still held small pockets of water during low tide, facilitating colonization by *Typha* spp. In the midsection of the island, tidal flooding across lower elevations created mudflat conditions where herbaceous aquatic and emergent species began to colonize. *Phalaris arundinacea* appeared to decrease in vigor (i.e., shoot, stem density, and reproductive capability), although no measurements were taken in this year.

In 1998 (Fig. 3d) few areas of permanent open water remained. Mudflats dominated in low elevation areas where open water once stood. Nonpersistent herbaceous emergent plant species increasingly colonized mudflat areas, and *P. arundinacea*-dominated communities were much reduced in areal extent from the prebreach condition. Stressed areas of *P. arundinacea* were characterized by reduced plant vigor and a mudflat/emergent understory. Between 1997 and 1998 the area of stressed *P. arundinacea* declined and was replaced by nonpersistent herbaceous emergent plant species.

Vigorous *P. arundinacea* stands persisted on site but were reduced by 50% in areal extent and were often interspersed with *Typha* spp. Total extent of *P. arundinacea* coverage was reduced by at least 20%, perhaps more given the lower stem density and greater amount of interspersion. Other communities with reduced area included forest and open water ponds. Increases since 1995 were observed in unvegetated mudflats, channels, and emergent and mixed communities.

Vegetation Studies

At least 61 plant species have been observed on Spencer Island in pre-and post-project monitoring (Table 2). Before dike breaching, the emergent marsh, which accounted for approximately 65% of the area of the site, contained only 5 of the 37 species on the site. *Phalaris arundinacea* was the most frequent plant species (89%), followed by *T. latifolia* (9%). Species richness was highest in the forested wetland; 35 of the 37 species on site were found. *Alnus rubra* (red alder) was the most frequent plant species encountered (19%), followed by *Rubus* spp. (blackberry) (16%). The other 33 plant species each had percent frequency values less than 10%.

The number of plant species encountered in sampling units decreased to 14 in 1995 (Table 2). This drop in richness reflects the reduction of sampling in the transition and forested areas and loss of species that could not tolerate the new hydrologic conditions. By 1998 plant species richness had increased to 38 species (Table 2). Except for *P. arundinacea* and *Typha* spp., species tended to be distributed sparsely and patchily throughout the site; it is difficult to estimate precisely the abundance of these species with the transect sampling design. For example, *Sagittaria latifolia* (wapato) was observed in moderate abundance at the site but was not encountered in the sampling units. Similarly, *Lythrum salicaria* (purple loosestrife) was visually observed along the margins of the project area in small patches but did not appear in the samples.

All the canopy species in the forested area died, and a variety of herbaceous emergent wetland species colonized this area. Frequently observed new plant species included *Alisma plantago aquatica* (broadleaf water-plantain), *Oenanthe sarmentosa* (water-parsley), *Sparganium emersum* (narrowleaf burreed), *Callitriche heterophylla* (water-chickweed), and *Bidens cernua* (beggarticks). *Phalaris arundinacea* continues to be very abundant within the restored area; however, its frequency declined to approximately 25%. Although no quantitative measures of plant vigor were taken, visual impressions of authors who sampled the site repeatedly were that stem height of *P. arundinacea* has declined (L. Tear & J. Rubey, 2001, personal communication).

Fish Assemblage

In 1997 seven species of fish and a total of 368 individuals were captured (Table 3); individuals were dominated numerically by *Oncorhynchus keta* (chum salmon). Chum salmon were captured either in the distributary channel or near the large breach, where 100 fish were captured in a single sampling event. *Mylocheilus caurinus* (peamouth chub) were the second most commonly observed species and were distributed evenly across later sampling dates (May and June) and throughout the three habitats. *Oncorhynchus kisutch* (coho salmon) were third most common and were more common later in the sampling period. Distribution of coho was even across the habitats.

Table 2. List of plant species sampled on Spencer Island, Washington, 1994–1998.

Latin Name	*Common Name*	*Habit*	*Year Species Sampled On Spencer Island*			
			1994	*1995*	*1997*	*1998*
Acer circinatum	Vine maple	S	X			
Agrostis gigantea	Redtop	G	X	X		
Alisma plantago-aquatica	Broadleaf water-plaintain	H			X	X
Alnus rubra	Red alder	T	X			
Aster subspicatus	Douglas aster	H				X
Athyrium filix-femina var. *cyclosorum*	Lady fern	F	X	X		
Bidens cernua	Nodding beggarticks	H			X	X
Callitriche heterophylla	Different leaved water-starwort	H				X
Carex deweyana var. *Deweyana*	Dewey sedge	Se	X			
Cares obnupta	Slough sedge	Se				X
Carex sp.	Unknown sedge	Se	X	X		X
Carex stipata	Sawbeak sedge	Se			X	X
Carex vesicaria var. *Major*	Inflated sedge	Se	X			
Cinna latifolia	Woodreed	G	X			
Elodea sp.	Unknown waterweed	H		X	X	
Epilobium cilatum	Watson willowherb	H	X		X	X
Festuca sp.	Unknown fescue	G				X
Gallium trificum var. *Pacificum*	Pacific bedstraw	H				X
Glyceria sp.	Unknown mannagrass	G	X	X	X	X
Holcus lanatus	Common velvetgrass	G	X			
Impatiens noli-tangere	Yellow touch-me-not	H			X	X
Juncus acuminatus	Tapertip rush	R				X
Juncus effusus	Soft rush	R	X	X		X
Juncus ensifolius	Daggerleaf rush	R		X		
Juncus sp.	Unknown rush	R			X	
Lemna minor	Small duckweed	H	X		X	X
Lysichiton americanum	Skunk-cabbage	H	X	X	X	X
Maianthemum dilatatum	Wild lily-of-the-valley	H	X			
Menta arvensis var. *villosa*	Field mint	H				X
Oenanthe sarmentosa	Water-parsley	H	X	X	X	X
Phalaris arundinacea	Reed canarygrass	G	X	X	X	X
Picea sitchensis	Sitka spruce	T	X	X		
Poa sp.	Unknown bluegrass	G	X			
Polygomun hydropiperoides var. *Hydropiperoides*	Mild waterpepper	H			X	X
Potamogeton natans	Floating-leaved pondweed	H	X	X	X	
Pteridium aquilinum var. *Pubescens*	Bracken fern	F	X			
Ranunculus repens var. *repens*	Creeping buttercup	H	X			X
Ranunculus sp.	Unknown buttercup	H			X	
Rorippa islandica	Marsh yellow cress	H			X	
Rubus sp.	Unknown blackberry	S	X		X	X
Rubus laciniatus	Evergreen blackberry	S	X			
Rubus spectabilis var. *Spectabilis*	Salmonberry	S	X	X		X
Rubus ursinus	Trailing blackberry	S	X			X
Rumex crispus	Curly dock	H				X
Sambucus racemosa ssp. *pubens*	Red elderberry	S	X			
Scirpus altrocinctus	Wooly sedge	S				X
Scirpus cernuus	Low clubrush	S				X
Scirpus microcarpus	Small-fruited bulrush	S	X		X	X
Solanum nigrum	Black nightshade	H				X
Solanum dulcamara	Bittersweet nightshade	H	X		X	X
Sparganium emersum ssp. *emersum*	Narrowleaf burreed	H				X
Spiraea douglasii	Douglass spirea	S	X			X
Triglochin maritima	Seaside arrowgrass	H			X	X
Typha angustifolia	Narrowleaf cattail	H				X
Typha latifolia	Broad-leaf cattail	H	X	X	X	X
Urtica dioica ssp. *gracilis* var. *lyallii*	Stinging nettle	H	X			X
Veronica americana	American brooklime	H	X		X	X
	Unidentified fern		X			X
	Unidentified herb no. 1		X			
	Unidentified herb no. 2		X			
	Unidentified moss		X			
Total number of species			37	14	22	38

T, tree; H, herb; G, grass; Se, sedge; F, fern; R, rush. Nomenclature follows Kartesz (1994).

Table 3. Annual results of fish sampling on Spencer Island, Washington, 1997–1999.

		Total Number Sampled on Spencer Island		
Latin Name	*Common Name*	*1997*	*1998*	*1999*
Gasterosteus aculeatus	threespine sticklback	6	507	517
Lepomis macrochirus	bluegill		3	
Leptocottus armatus	staghorn sculpin		2	3
Mylocheilus caurinus	peamouth chub	112	145	265
Oligocottus rimensis	prickly sculpin		1	1
Oncorhynchus clarki	cutthroat trout		1	
O. gorbuscha	pink salmon	1	15	
O. keta	chum salmon	225	174	644
O. kisutch	coho salmon	16	59	29
O. mykiss	steelhead trout	3	1	
O. tschawytscha	chinook salmon	4	148	39
Platichthys stellatus	starry flounder		5	42
Salvelinus sp.	unknown char	1		
	Unknown sculpin		13	1
Rana sp.	unknown tadpole		1	4
Primary sampling gear used		Gill nets	Beach seines	Beach seines
Sampling period		4 Mar–18 Jun	3 Apr–12 Jun	2 Apr–10 Jun

In 1998 1,074 individuals comprising 13 species were captured. *Gasterosteus aculeatus* (threespine stickleback) was the most abundant species with 507 individuals collected. The next most common species were chum salmon, *O. tschawytscha* (chinook salmon), and peamouth chub. Other salmonids were less common.

Eleven species of fish were caught during the 1999 sampling effort. Chum salmon dominated the overall catch, and most of these (399) were caught in a single beach seine haul in mid-April. Threespine stickleback were the second most abundant fish caught, and most of these (318) were also caught in mid-April. Peamouth chub were also relatively abundant, with most of their number occurring toward the end of the sampling season. Overall catches of other salmonids were relatively small in comparison with chum salmon.

Invertebrates

Results of benthic and fallout insect sampling in 1997 are partially presented in Simenstad and Cordell (2000) and presented in detail in Cordell et al. (1998). On the basis of two measures of diversity, taxa richness and the Shannon-Weiner index, benthic assemblages at each habitat of the breached-dike restored site were less diverse than those at the reference sites. The restored habitats had an average of 2.5 fewer taxa per site than did those at the reference site. However, based on percent numerical composition, restored and reference benthic invertebrate assemblages were quite similar in being numerically dominated by nematode and oligochaete worms. In addition, two families of dipteran fly larvae that are important juvenile salmon prey occurred in relatively high proportions at the restoration site wooded edge (ceratopogonids) and mudflat (chironomids). Similarly, overall densities per unit area of these two taxa were abundant relative to reference densities at the same restoration site habitats.

Diversity of adult insects from the fallout traps increased from March to May in restoration site habitats; this trend did not occur at the reference site. In March and April diversity was markedly lower in the *P. arundinacea* marsh at the restoration site than at the reference *Carex* marsh. Similarly, the reference site wooded edge samples had higher Shannon-Weiner indices (but similar taxa richness) than did those from the restoration site wooded edge. In percent numerical composition chironomid flies dominated the fallout insect catches in March in all habitats. Insect numbers at the reference site were usually distributed relatively evenly among three to seven taxa. In contrast, at the restoration site composition consisted almost entirely of one to three taxa.

Two taxa were largely site specific: Collembola (springtails) were only prominent at the reference site *Carex* and wooded edge habitats, and Ephydridae (dipteran flies) occurred exclusively at the three restoration site habitats. Three dipteran fly taxa made up most of the important salmon prey from fallout traps at both the restored and reference sites. Chironomids were especially abundant at the restoration site wooded edge, where they reached a peak density of approximately 5.0×10^3 individuals/m^2 in April, approximately five times higher than at any other site and time. Ephydrid flies occurred almost exclusively in the three restoration site habitats, where their abundance peaked dramatically in May.

Although psychodid flies were abundant at both restoration and reference sites, they were usually most abundant at one of the two reference site habitats.

Juvenile Salmon Diets

In 1997 diets were analyzed from 56 chum and 19 coho salmon. Results are partially presented in Simenstad and Cordell (2000) and presented in detail in Cordell et al. (1998). Emergent adults and pupae of chironomid flies dominated the prey weight in juvenile chum salmon at every site and date analyzed except on one occasion when a group of chum captured near the large breach had fed mainly on the mysid shrimp *Neomysis mercedis*. Prey in coho salmon on the first two of the three dates analyzed (8 and 26 May) was distributed among a relatively large number of taxa. Chironomid flies were still the dominant taxon at about 50% of the prey weight, but the remainder of the prey weight was distributed into a variety of other insect categories, the most abundant of these being Tipulidae (craneflies), Ephemeroptera (mayfly) nymphs, and Coleoptera (beetles).

As with the juvenile chum analyzed in 1997, diets of the 68 chum analyzed from 1998 were dominated by chironomids (Fig. 4). In contrast to the chum diets, prey weight in the 40 coho salmon analyzed was dominated by crustaceans (Fig. 5). One or two crustacean taxa dominated the diet at each site per date: *Neomysis mercedis* at the breach site on 17 April; *Corophium* spp. at both mudflat sites on 15 May; and *Corophium* spp., the gammarid amphipod *Eogammarus confervicolus*, and *Daphnia* spp. cladocerans at the mudflat sites on 29 May. Insects dominated coho diets only at the large breach site on 29 May, in which case prey consisted of fly larvae and a variety of other insects. Diet composition of juvenile chinook

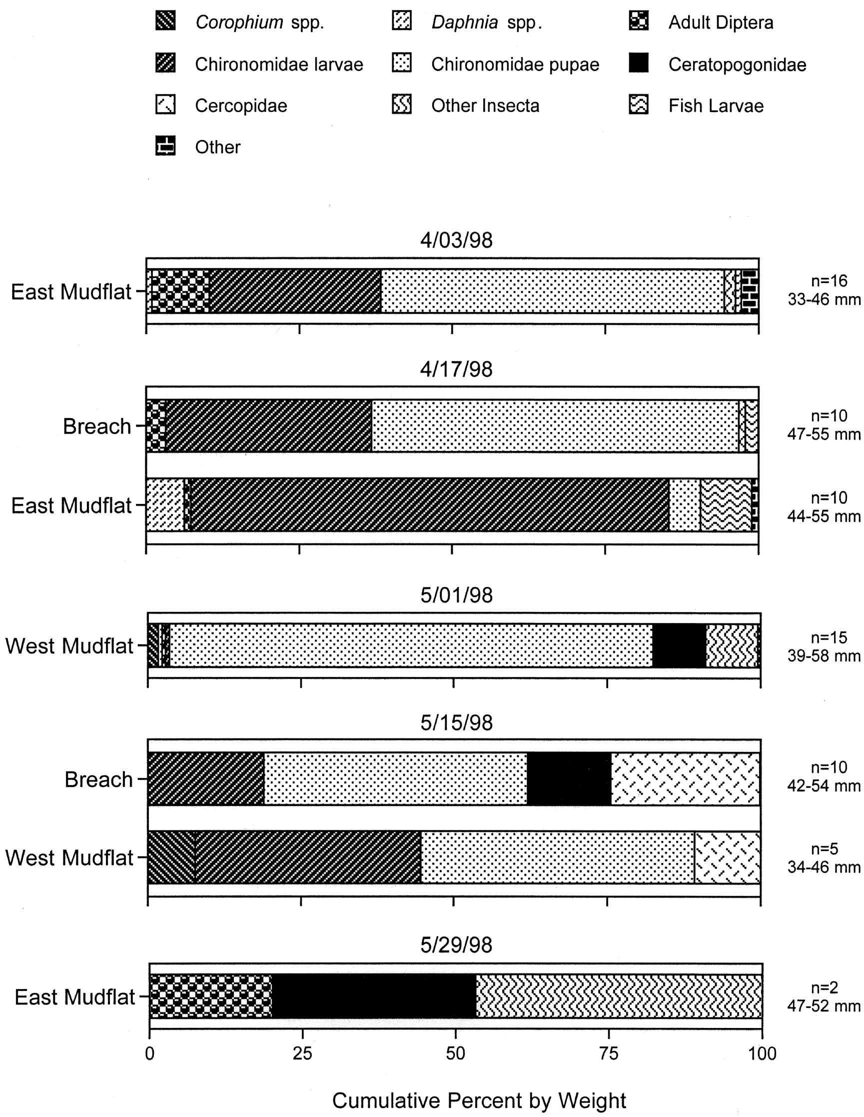

Figure 4. Percentage composition by weight of prey from juvenile chum salmon on five dates at several stations at Spencer Island, Washington.

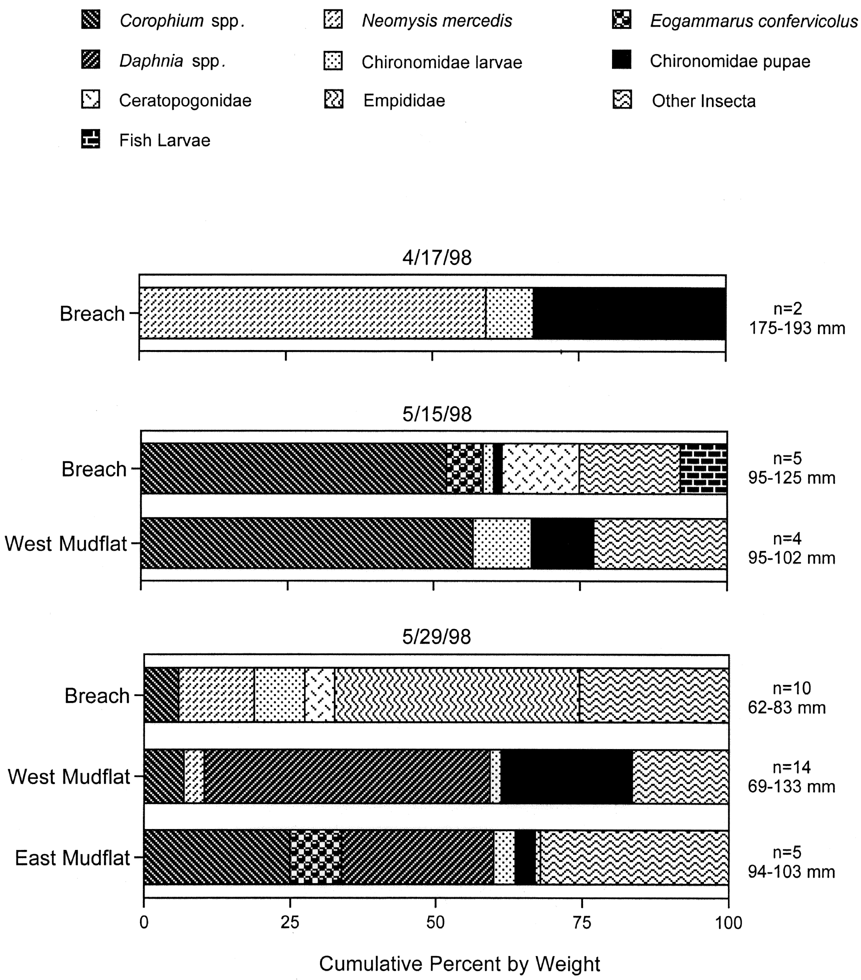

Figure 5. Percentage composition by weight of prey from juvenile coho salmon on five dates at several stations at Spencer Island, Washington.

salmon (71 analyzed) was more varied than for chum and coho (Fig. 6). In early April diet was dominated by the amphipods *Corophium* spp. and larval fish at the east mudflat site. In late April chironomid fly larvae, larval fish, and *Corophium* spp. were the predominant prey taxa. In May sample dates chironomid larvae and pupae dominated the diets from chinook caught at the mudflat sites, whereas at the breach site prey was distributed into relatively more taxa, including the mysid shrimp *Neomysis mercedis*, ceratopogonid fly larvae and pupae, and cercopid insects (leaf hoppers). In the 12 June sample ceratopogonid fly larvae and pupae were dominant.

Discussion

Subsequent to dike breach restoration of Spencer Island the physical and biological conditions at the site changed, and continue to do so. Vegetation that dominated before breach have begun to either decrease in frequency or die back altogether. New plant species were recruited into available open spaces.

In 1998 *P. arundinacea* and *T. latifolia* continued to dominate the western one-third of the site; *P. arundinacea* appeared less vigorous, but *T. latifolia* patches appeared to be unaffected. Increases in the area of vigorous *P. arundinacea* in 1997 as compared with 1995 might represent acclimation from the initial stress of inundations or minor variations in the interpretation of vigorous versus stressed community signatures from aerial photographs. *Phalaris arundinacea* and *T. latifolia* wrack have accumulated in multiple areas around the site. Intertidal mudflats and nonpersistent herbaceous emergent classes have appeared in the central area of the site replacing the pre-breach standing water ponds and much of the stressed *P. arundinacea* community.

The reduction in vigorous *P. arundinacea* has resulted in higher plant diversity and new species assemblages. Slight differences in elevation across the site have contributed to a gradation (low to higher) from unvegetated to vegetated mudflats, *P. arundinacea* with an emergent mudflat understory, *P. arundinacea* and *Typha* spp. marsh to a mixed persistent emergent and shrub assemblage. A multitude of new community expres-

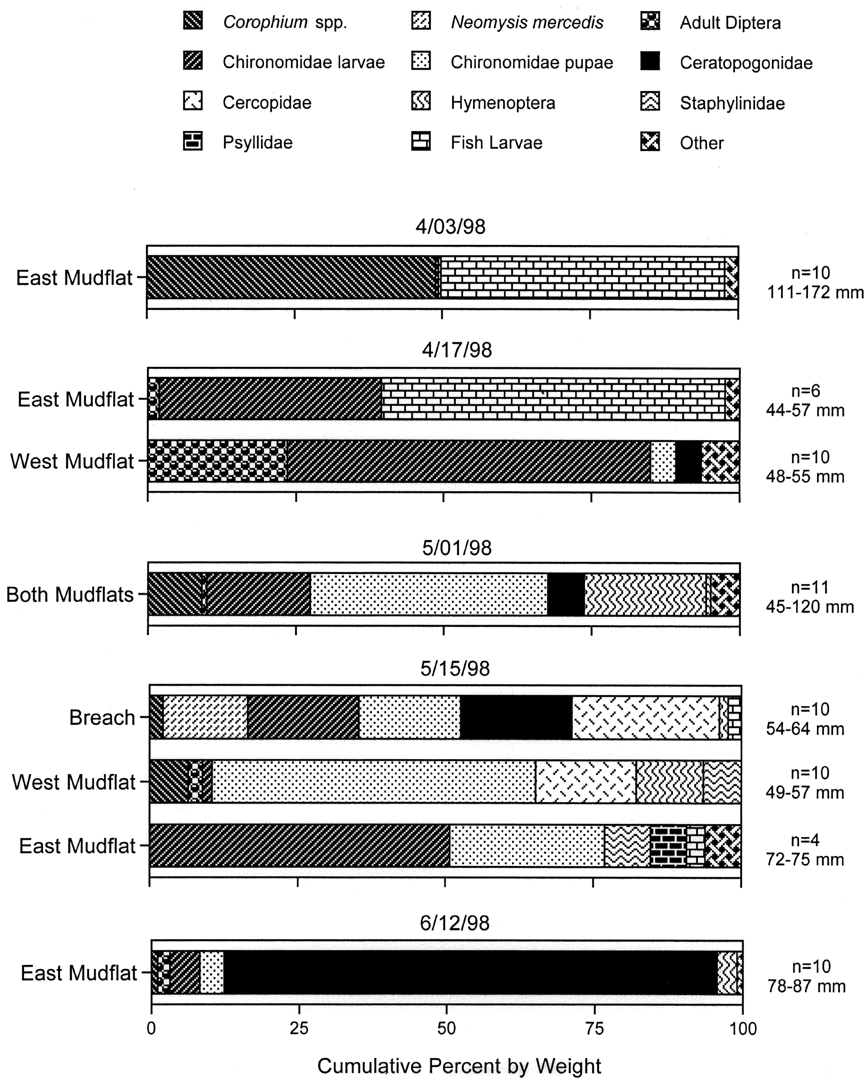

Figure 6. Percentage composition by weight of prey from juvenile chinook salmon on five dates at several stations at Spencer Island, Washington.

sions are present within these broader bands, demonstrating the complexity of restoration site succession.

Project partners are concerned that the integrity of the newly developing native freshwater intertidal plant community may be threatened by the appearance of *L. salicaria.* Concern about this invasive plant species has lead to control efforts, including manual pulling and introduction of the biological control beetle *Galerucella* spp. Invasion by exotic species is a potential problem facing many restoration projects. Anticipating this and other challenges must become part of the planning process for all restoration projects.

Measuring the benefits to juvenile salmon from restored estuarine habitats is notoriously difficult because of their episodic and transitory residence and problems with directly measuring "realized function" (e.g., increased growth rates and survival) (Simenstad & Cordell 2000). However, two other restoration assessment criteria, capacity and opportunity, are more tractable (Simenstad & Cordell 2000), and Spencer Island data have been examined in light of these criteria.

One important measure of the capacity of a restored habitat for juvenile salmon use is the availability and quantity of invertebrate prey. The data suggest that despite its early state of development, the restoration site at Spencer Island already provides this function. First, juvenile salmon foraging at the site had diets dominated by chironomids and several other prey taxa typical of those found in estuarine habitats elsewhere in the Pacific Northwest (Congleton 1978; Northcote et al. 1979; Levings et al. 1995; Cordell et al. 1997; Miller & Simenstad 1997). Chironomids also dominated the prey of juvenile salmon captured at the restoration site in 1999 (Cordell et al. 2001). These prey taxa were also relatively abundant in invertebrate samples from the restoration site. Second, documented salmon prey invertebrates collected in the benthic cores and fallout traps often had comparable or higher relative abundance at the restoration site as compared with the reference site. Third, all three species of juvenile salmon analyzed had relatively high stomach fullness indices (Cordell et al. 1999).

Opportunity metrics that appraise the capability of juvenile salmon to access and benefit from a habitat include tidal elevation and flooding, habitat complexity, and refugia from predation (Simenstad & Cordell 2000). After dikes were breached at Spencer Island the site was accessed by juvenile salmon and other fish (Cordell et al. 1998, 1999, 2001). Although the predator refuge aspect of the site was not examined, presence of a diverse emergent plant community on site and the diked condition of much of the Snohomish estuary elsewhere suggests the site may provide a refuge opportunity for juvenile salmon.

The presence and apparent use of the site by juvenile coho salmon was unanticipated. Use of tidal estuaries by this species has not been extensively reported. This may in part be due to the relative lack of knowledge regarding the freshwater component of tidal ecosystems, as compared with oligo- and mesohaline marshes and mudflats.

The composition of Spencer Island habitats continues to be in transition. Ephydrid flies occurred exclusively within restoration site habitats. Observations from other restoration sites suggest that this taxon may be transitory, abundant only early in site development or at disturbed sites (Cordell et al. 1997). Other researchers who compared soil insect communities between the tidal and nontidal (south and north, respectively) portions of Spencer Islands also observed relatively low insect species diversity within the tidal marsh. They hypothesized that the relative stability of water levels in the nontidal marsh contributed to a more diverse assemblage of insects. Predation by fish in the tidal marsh was also given as a possible explanation for lower insect abundance (Hansen & Castelle 1999).

Vegetation and invertebrate assemblages suggest the lack of saline inputs at the Spencer Island restoration site. In 1995 measurements taken nearby in the eastern breach on Steamboat Slough in July and August detected only occasional near-bottom salinity (B. Feist, L. Tear, and C. Simenstad, University of Washington School of Aquatic and Fisheries Sciences, unpublished data). Water column and soil salinity measurements taken during March and April 1999 at the reference site ranged from 0.1 to 1.5 ppt. Salinity was below detection limits near Spencer Island in the vicinity of the primary breach on Union Slough and did not change with depth (D. Mathias & M. Matthies, unpublished data).

Abundance of estuarine polychaete worms and benthic crustaceans is low compared with other Pacific Northwest brackish and oligohaline estuaries (Simenstad et al. 1992, 1993; Simenstad & Thom 1996; Cordell et al. 1994, 1996, 1997) and compared with the reference site. Instead, the site is dominated by invertebrate taxa typical of freshwater sites, including nematodes, oligochaetes, chironomid larvae, and freshwater isopods. Finally, vegetation communities at the reference site are dominated by *C. lyngbyei*, *Scirpus acutus*, and *T. latifolia*, (Cunningham & Polayes-Wein, unpublished data), plants typically associated with brackish marshes in the Pacific Northwest. Plant species colonizing the project area indicate predominantly freshwater conditions, with the exception of *T. latifolia*, which was present on the project site before dike breaching and often associated with freshwater wetlands.

Conclusions

As one of the first breached-dike restoration projects completed in the Puget Sound region, the Spencer Island site has served to demonstrate a relatively low cost high benefit strategy for restoring estuarine habitat. We have learned valuable lessons that as of 2002 are being applied to other restoration projects in the region.

Initial project planning and design anticipated that the created habitat would be a brackish marsh system. Instead, results suggest that the site is developing into a freshwater tidal system. Despite this miscalculation of site trajectory the project appears to be providing important ecological function. First, it is being colonized by a plant assemblage characteristic of tidal fresh water, a habitat that has become uncommon in our region due to human impacts in estuaries. Second, invertebrate assemblages and densities were similar to those found at within-estuary reference sites and other estuaries in the region. Third, breaching of the dikes resulted in access by several species of juvenile salmon and other fish and fish from the site fed on prey characteristic of natural wetlands in the Puget Sound region.

Post-project monitoring has been a mixture of achievements and limitations. Limited and variable funding available for monitoring forced difficult trade-offs such as one-time sampling (invertebrates), year-to-year changes in methodology or intensity of effort (vegetation), and dropping of some proposed efforts. However, repeated within-year and among-year site visits provided valuable insights as to the project trajectory, allowing adaptive management at the site for biological threats such as invasive plant species.

Acknowledgments

We thank Susan Grigsby for her completion of GIS tasks. Rich Daniels and Robert Huxford assisted in photo image conversion. Marcus Duke and Cathy Schwartz made the figures work. Kevin Aitkin coordinated fish sampling efforts. Assistance with fieldwork was provided by Ayesha Gray, Andy Haas, Steve Hager, James Kim, Dave Low, Victoria Luiting, Kate O'Keefe, Eric Reader, Paul Renaud, Linda Storm, Jason Toft, and Matthew Wood. Heather Higgins assisted in the field, prepared figures, and analyzed insect fallout trap data. Michael Rylko, Dave Shreffler, Charles Simenstad, Ron Thom, and Fred Weinmann provided invaluable assistance in the early phases of monitoring program development. Support for this research was provided by the National Oceanic and Atmospheric Administration Coastal Zone Management Program, Snohomish County Parks and Recreation, U.S. EPA Region X, U.S. Fish and Wildlife Service Puget Sound Program, and the Washington Department of Ecology.

LITERATURE CITED

Bortleson, G. C., M. J. Chrzastowski, and A. K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound region, Washington. Hydrologic Investigations Atlas HA-617. Department of the Interior, United States Geological Survey, Reston, Virginia.

Congleton, J. L. 1978. Feeding patterns of juvenile chum in the Skagit River salt marsh. Pages 141–150 in C. A. Simenstad and S. J. Lipovsky, editors. Fish Food Habits Studies First Pacific Northwest Technical Workshop, Workshop Proceedings, Washington Sea Grant. University of Washington, Seattle. WSG-WO-77-2.

Cordell, J. R., L. M. Tear, C. A. Simenstad, S. M. Wenger, and W. G. Hood. 1994. Duwamish River Coastal America restoration and reference sites: results and recommendations from year one pilot and monitoring studies. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9416, Seattle.

Cordell, J. R., L. M. Tear, C. A. Simenstad, and W. G. Hood. 1996. Duwamish River Coastal America restoration and reference sites: results from 1995 monitoring studies. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9612, Seattle.

Cordell, J. R., L. M. Tear, K. Jensen, and V. Luiting.1997. Duwamish River Coastal America restoration and reference sites: Results from 1996 monitoring studies. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9609, Seattle.

Cordell, J. R., J. Higgins, C. Tanner, and J. K. Aitken. 1998. Biological status of fish and invertebrate assemblages in a breached-dike wetland site at Spencer Island, Washington. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9805, Seattle.

Cordell, J. R., C. Tanner, and J. K. Aitkin. 1999. Fish assemblages and juvenile salmon diets at a breached-dike wetland site, Spencer Island, Washington 1997–98. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9905, Seattle.

Cordell, J. R., M. Stamey, C. Tanner, and J. K. Aitkin. 2001. Fish assemblages and juvenile salmon diets at a breached-dike wetland site, Spencer Island, Washington 1999. University of Washington School of Aquatic and Fishery Sciences. SAFS-UW-0104, Seattle.

Greig-Smith, P. 1964. Quantitative plant ecology. 2nd edition. Butterworths, London.

Hansen, J. D., and Castelle, A. J. 1999. Insect diversity in soils of tidal and non-tidal wetlands of Spencer Island, Washington. Journal of the Kansas Entomological Society **73:**262–272.

Kartesz, J. T. 1994. A synonymized checklist of the vascular flora of the United States, Canada, and Greenland. 2nd edition, 2 volumes. (Checklist and Thesaurus). Timber Press, Portland, Oregon.

Levings, C. D., D. E. Boyle, and T. R. Whitehouse. 1995. Distribution and feeding of juvenile Pacific salmon in freshwater tidal creeks of the lower Fraser River, British Columbia. Fisheries Management and Ecology **2:**299–308.

Miller, J. A., and C. A. Simenstad. 1997. A comparative assessment of a natural and created estuarine slough as rearing habitat for juvenile chinook and coho salmon. Estuaries **20:** 792–806.

Northcote, T. G., N. T. Johnston, and K. Tsumura. 1979. Feeding relationships and food web structure of lower Fraser River fishes. Westwater Research Center Technical Report 16. University of British Columbia, Vancouver.

Puget Sound Water Quality Authority. 1991. 1991 Puget Sound Water Quality Management Plan. Puget Sound Water Quality Authority. Olympia, Washington.

Puget Sound Water Quality Action Team. 2000. 2000 Puget Sound Water Quality Management Plan. Puget Sound Water Quality Action Team. Olympia, Washington.

Simenstad, C. A., C. D. Tanner, R. M. Thom, and L. L. Conquest. 1991. Estuarine habitat assessment protocol. EPA 910/9-91-037. Report to the U.S. Environmental Protection Agency, Region 10, Seattle, Washington.

Simenstad, C. A., J. R. Cordell, J. A. Miller, W. G. Hood, and R. M. Thom. 1992. Ecological status of a created estuarine slough in the Chehalis River estuary: assessment of created and natural estuarine sloughs, January–December 1991. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9206, Seattle.

Simenstad, C. A., J. R. Cordell, J. A. Miller, W. G. Hood, and R. M. Thom. 1993. Ecological status of a created estuarine slough in the Chehalis River estuary: assessment of created and natural estuarine sloughs, January–December 1992. University of Washington School of Fisheries, Fisheries Research Institute. FRI-UW-9305, Seattle.

Simenstad, C. A., and R. M. Thom. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecological Applications **6:**38–56.

Simenstad, C. A., and J. R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering **15:**283–302.